



Primary School Teachers' Readiness to Address the Transformation of Science Education through Artificial Intelligence: A Systematic Literature Review

Tia Nabela ^{1*}, Rohmani ²

¹Elementary School Teacher Education Program, Faculty of Teacher Training and Education, Muhammadiyah University of Kotabumi, Jl. Hasan Kepala Ratu, Lampung, Indonesia

²Elementary School Teacher Education Program, Faculty of Teacher Training and Education, Muhammadiyah University of Kotabumi, Jl. Hasan Kepala Ratu, Lampung, Indonesia

*Corresponding author: tianabela17@gmail.com

Abstract: Science education in elementary schools is still dominated by conventional methods, which are thus unable to optimally foster student engagement and conceptual understanding. Advances in Artificial Intelligence (AI) offer opportunities to transform learning into a more interactive and adaptive experience; however, its success depends heavily on teacher readiness. This study aims to describe and analyze the readiness of elementary school teachers to address the transformation of science education through AI. The method used is a Systematic Literature Review (SLR) employing the PRISMA approach, involving a search of articles in the Scopus database from 2021 to 2025, which were then screened to identify 10 relevant and high-quality articles. The results indicate that, in general, teachers exhibit positive attitudes, high interest, and good acceptance toward the use of AI in learning. However, in terms of technical and pedagogical competencies, teachers' readiness remains at a moderate level and is not yet uniform. Limited digital literacy, a lack of training, and insufficient infrastructure support are the main obstacles. Therefore, it is concluded that elementary school teachers' readiness to face AI-based science learning transformation falls into the "sufficiently prepared" category; however, it still requires improvement through continuous training, competency enhancement, and support in facilities and policies so that AI implementation can proceed optimally and sustainably

Keywords: Science, Artificial Intelligence, Elementary School

Abstrak: Pembelajaran IPA di sekolah dasar masih didominasi metode konvensional, sehingga kurang mampu mengembangkan keterlibatan dan pemahaman konsep siswa secara optimal. Perkembangan Artificial Intelligence (AI) menawarkan peluang transformasi pembelajaran menjadi lebih interaktif dan adaptif, namun keberhasilannya sangat bergantung pada kesiapan guru. Penelitian ini bertujuan guna menggambarkan dan menganalisis kesiapan guru sekolah dasar untuk menghadapi transformasi pembelajaran IPA melalui AI. Metode yang digunakan yaitu Systematic Literature Review (SLR) melalui pendekatan PRISMA, melalui penelusuran artikel pada basis data Scopus tahun 2021–2025, yang kemudian diseleksi hingga diperoleh 10 artikel yang relevan dan berkualitas. Hasil penelitian menunjukkan bahwa secara umum guru memiliki sikap positif, minat tinggi, serta penerimaan yang baik terhadap penggunaan AI dalam pembelajaran. Namun, dari aspek kompetensi teknis dan pedagogis, kesiapan guru masih berada pada tingkat sedang dan belum merata. Keterbatasan literasi digital, kurangnya pelatihan, serta minimnya dukungan infrastruktur menjadi kendala utama. Maka disimpulkan, kesiapan guru sekolah dasar dalam menghadapi transformasi pembelajaran IPA berbasis AI berada pada kategori cukup siap, tetapi masih memerlukan peningkatan melalui pelatihan

berkelanjutan, penguatan kompetensi, serta dukungan sarana dan kebijakan agar implementasi AI dapat berjalan secara optimal dan berkelanjutan

Kata kunci: *IPA, Artificial Intellegence, Sekolah Dasar*

▪ INTRODUCTION

Science education in elementary school plays a crucial role in developing students' conceptual understanding and critical thinking skills (Hanafi & Komalasari, 2025; Sidabalok et al., 2025). Science is not merely focused on understanding the subject matter, but on the scientific process involving observation, experimentation, and reasoning (Angelia et al., 2022; Hariyanto et al., 2025). However, the reality in the field indicates that science lessons still focus on conventional methods such as lectures and rote memorization (Orujlu, 2025; Parno & Agustinus, 2022). This results in students being passive, less engaged in teaching and learning activities, and facing difficulties in connecting concepts to their daily lives.

The development of digital technology, particularly Artificial Intelligence (AI), presents significant opportunities to transform science education into a more innovative and interactive experience (Naimah, 2022; Purba et al., 2025). AI enables personalized, adaptive learning and is capable of providing rapid feedback to students (Alkan, 2024; Shambhavi et al., 2025). In the context of science education, AI can be utilized to visualize abstract concepts, conduct experimental simulations, and support data-driven learning (Boltaeva, 2025; Hariyanto et al., 2025). Consequently, the use of AI has the potential to enhance students' conceptual understanding and engagement in teaching and learning activities.

Although AI holds great potential in the field of education, the success of its implementation depends on teachers' readiness to serve as the primary facilitators of teaching and learning activities (Alshorman, 2024; Sadykova & Kayumova, 2024). Teacher readiness encompasses not only the technical skills to apply technology but also pedagogical understanding and a positive attitude toward learning innovations (Ismail et al., 2024; Nugroho et al., 2024). Teachers are required to be able to effectively integrate AI to support the achievement of science learning objectives (Cabral & Palavras, 2025; Octavio & Leocadio, 2025). Thus, teacher readiness is a key factor in the success of AI-based learning innovation transformation in elementary schools.

In reality, not all teachers are adequately prepared to deal with technological advancements, particularly AI (Azim, 2025; Rahangmetan et al., 2025). Some of the obstacles frequently encountered include limited digital literacy, a lack of training, and insufficient facility support from schools (Anwar et al., 2025; Rustandi et al., 2024). Furthermore, there are still teachers who hold negative perceptions or have reservations about the use of technology in learning. These conditions have resulted in the use of AI in science education not yet being optimal and not yet being evenly distributed across various elementary schools.

Several previous studies have indicated that the integration of technology into teaching activities can have a positive impact. The first study by Hashim et al., (2022) found that the use of AI can enhance the personalization of learning and improve student learning outcomes. The study by Pazmiño et al., (2024) found that the use of digital technology can boost student motivation and engagement in learning activities. A third study by Aprianto et al., (2025) revealed that the integration of innovative technologies, including AI, can improve students' critical thinking and problem-solving skills. However, these studies still focus on the implementation of technology in learning and have not yet thoroughly examined teacher readiness as a key factor in the successful application of AI.

The development of AI technology presents new challenges for the world of education, particularly for elementary school teachers who are expected to adapt to technology-based learning changes. However, the lack of systematic studies on teacher readiness often results in suboptimal AI implementation in the field. Important aspects such as pedagogical competence, digital literacy, attitudes toward technology, limited training, and facility support still need to be thoroughly examined so that the use of AI can be effective and does not create learning gaps.

This study is novel because it employs the Systematic Literature Review (SLR) method to analyze teachers' global readiness to address the transformation of science education through AI. Unlike previous studies that have primarily focused on the effectiveness of AI on student learning outcomes, this study focuses on teachers' readiness as the primary implementers of learning. The SLR approach, utilizing internationally reputable literature sources, enables a more comprehensive understanding of the aspects of knowledge, skills, attitudes, and implementation challenges of AI across various educational contexts.

Based on this, the research question is: How prepared are elementary school teachers to address the transformation of science education through AI? The research objectives are to describe and analyze teachers' readiness to integrate AI, identify the factors influencing it, and provide a foundation for developing effective, innovative, and sustainable AI implementation strategies in science education at the elementary school level

▪ METHOD

This study employs a Systematic Literature Review (SLR) approach, utilizing data from the Scopus database and adhering to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines as a systematic framework to enhance transparency and accuracy in the process of identifying, screening, and synthesizing scientific articles relevant to the research topic (Ulfha et al., 2025). The purpose of the SLR approach in this study is to present comprehensive and objective knowledge regarding the results of previous research on elementary school teachers' readiness to face the transformation of science learning innovation through AI, while also identifying research gaps and providing direction for future research (Ratih et al., 2025).

Data collection for this study was conducted through a literature search in the Scopus database, which serves as the primary source due to its international reputation and provision of high-quality scientific articles. The search process utilized a combination of keywords relevant to the research topic, namely ("Science Education" OR "Science Learning"), ("Artificial Intelligence" OR "AI"), and ("Elementary School" OR "Primary School"). The search was limited to the publication years 2021 to 2025 to obtain an overview of the latest research developments related to the topic under study. Subsequently, the search results were filtered based on inclusion criteria, namely articles focusing on the use of AI in science learning, as well as relevance to the context of elementary education. Exclusion criteria included articles that did not align with the topic, were not available in full-text format, and data duplicates. The selection process was conducted in stages according to the PRISMA flowchart, resulting in a set of articles meeting the criteria for analysis in this study. The PRISMA flowchart involves identification, screening, and analysis, as shown in Figure 1.



Figure 1. Stages of a Systematic Literature Review

The search results from the Scopus database were then screened based on predetermined criteria, namely scientific articles relevant to the topic of elementary school teachers' readiness to face the transformation of science education based on Artificial Intelligence (AI), as well as those meeting adequate publication quality standards. Quality criteria were determined based on a minimum Scopus indexing with Q2 as an indicator of the article's impact and credibility within the Scopus database. Proceedings and non-article sources were excluded from the scope of this study. The selection process was conducted systematically through the identification, screening, eligibility evaluation, and inclusion steps outlined in the PRISMA guidelines, resulting in the selection of the ten most relevant articles for analysis. This number represents the final outcome of the systematic selection process of all initial findings in Scopus, while other articles were eliminated because they were indicated as duplicates, irrelevant to the topic, not focused on the elementary school level, or did not meet the established criteria.

Based on the review results, these ten articles demonstrated relatively consistent patterns of findings and were therefore deemed sufficiently representative to address the research objectives. These selected articles were subsequently used as the basis for the analysis in this study, as presented in Figure 2.

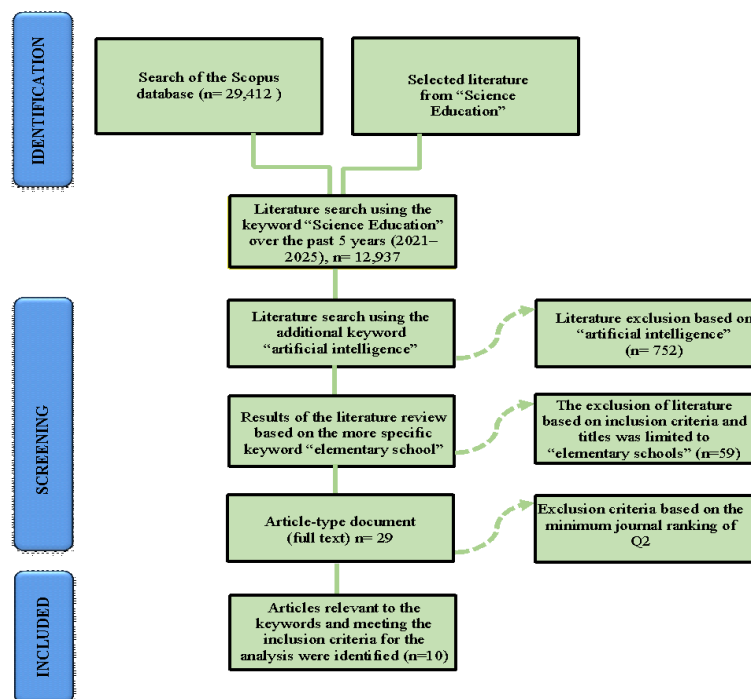


Figure 2. Stages of Inclusion Criteria

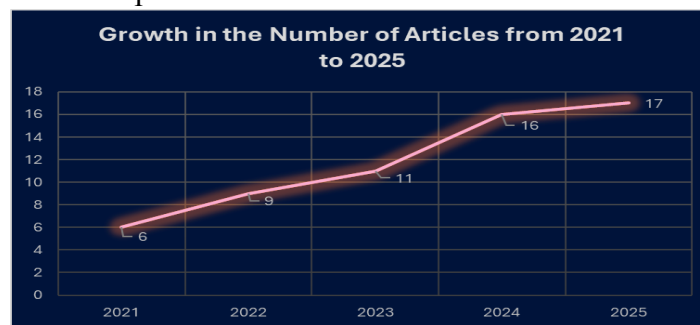
The figure illustrates the systematic stages of article selection in this study. During the identification stage, an initial search using the keywords (“Science Education” OR “Science Learning”) yielded 29,412 results, which were then filtered to

the years 2021–2025, resulting in 12,937 articles. Next, the search was narrowed by adding the keywords (“Artificial Intelligence” OR “AI”), yielding 752 articles. The subsequent stage involved adding the keywords (“Elementary School” OR “Primary School”), resulting in 59 more specific articles aligned with the study’s focus.

Following this, a screening phase was conducted by limiting the publication year to the 2021–2025 range and selecting articles based on the relevance of their titles and abstracts. In the analysis stage, articles were reselected based on quality criteria, namely being indexed in Scopus with a Q2 ranking as an indicator of academic impact. Through this process, 10 articles that met the criteria were identified and used as the final analysis material in the study

▪ RESULT AND DISCUSSION

The data for this study were sourced from scientific articles identified through a search of the Scopus database, yielding an initial total of approximately 29,412 publications. The literature review focused on scientific articles relevant to elementary school teachers’ readiness to address the transformation of science education through AI. The search was conducted using a combination of keywords (“Science Education” OR “Science Learning”), (“Artificial Intelligence” OR “AI”), and (“Elementary School” OR “Primary School”), and was limited to the period 2021–2025 to identify research trends, as presented in Graph 1.

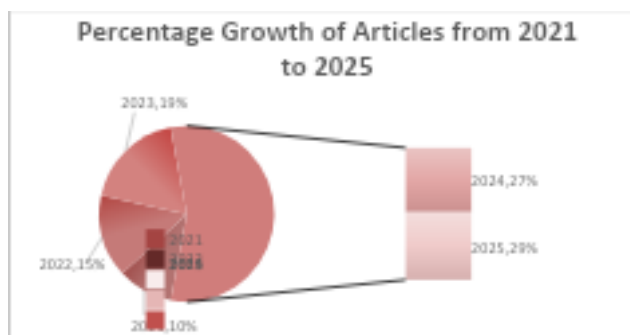


Graph 1. Growth in the Number of Articles from 2021 to 2025

As shown in Figure 1, the number of Scopus-indexed articles has shown a consistent increase from 2021 to 2025. In 2021, there were 6 publications, which increased to 9 in 2022. This upward trend continued in 2023 with 11 publications and saw a more significant surge in 2024 to 16 publications. In 2025, the number of articles increased again, albeit not as sharply, reaching 17 publications. This pattern indicates growing interest and an increasing research contribution year over year, suggesting that the field of study has shown positive and sustainable development over the past five years. The following presents the calculation of the average (mean) number of article publications per year.

$$\tilde{x} = \frac{\text{Number of articles}}{\text{Number of years}} = \frac{59}{5 \text{ years}} = 11,8 \text{ articles}$$

Thus, based on the calculation of the average (mean) number of publications from 2021 to 2025, the average is 11.8 articles per year. Furthermore, the percentage of articles discussing elementary school teachers’ readiness to face the transformation of science learning innovation through Artificial Intelligence (AI) is presented in Graph 2.



Graph 2. Percentage Growth of Articles from 2021 to 2025

Based on the percentage chart of articles cited from the Scopus database on research topics during the period from 2021 to 2025, there is a variation in the contribution of publications each year. In 2021, the number of cited articles was 6, or about 10% of total publications; then in 2022, it increased to 9 articles, or about 15%. Furthermore, in 2023, there was another increase to 11 articles, representing 19%. A significant increase occurred in 2024, with the number reaching 16 articles, or approximately 27%. Meanwhile, in 2025, the number of articles recorded was 17, or 29%, which was the highest number in that period. Overall, these data indicate a very clear upward trend in researchers' interest and attention in examining teachers' readiness to face AI-based learning in elementary schools.

In line with the increasing trend of such publications in the Scopus database, this study further focuses on articles most relevant to the topic of elementary school teachers' readiness to address the transformation of science education through Artificial Intelligence (AI). Using a Systematic Literature Review (SLR) process with data sourced from the Scopus database, a systematic screening process was conducted to identify 10 articles from Scopus that met the inclusion and eligibility criteria for in-depth analysis. The results of the analysis of these selected articles are then presented in a table to provide a concise and structured description, as shown in the table below.

Table 1. Analysis Results on the Readiness of Elementary School Teachers to Face the Transformation of Science Learning through Artificial Intelligence

No	Title	Journal Name/Journal Status	Research Findings	Recommendations
1.	The Readiness to Use AI in Teaching Science: Science Teachers' Perspective (Alshorman, 2024)	Journal of Baltic Science Education /Q2	Teachers demonstrate a high level of interest in AI-based learning innovations, particularly to help explain complex science concepts. However, limited technical competencies and a lack of training support are the main barriers to its implementation in the classroom	Teachers' technical competencies need to be strengthened through workshops and guidance on using AI in science education, so that their readiness extends beyond mere attitude to include practical implementation skills in the classroom
2.	Application of artificial intelligence APP	Educational Studies/Q1	The use of AI applications in science education enables a more systematic	It is recommended to utilize AI applications as evaluation tools to

	in quality evaluation of primary school science education (Huang, 2022)		and accurate evaluation process, allowing teachers to clearly observe students' conceptual understanding and learning outcomes	obtain a more accurate picture of students' learning outcomes.
3.	Integrating artificial intelligence into science lessons: Teachers' experiences and views (Park et al., 2023)	International Journal of Science Education/ Q2	Teachers have a positive attitude and high interest in the use of AI, but their technical and pedagogical readiness still varies, particularly in terms of skills in operating technology and designing AI-based learning	There is a need for increased practice-based training to strengthen teachers' readiness, particularly in effectively integrating AI into science learning in elementary schools
4.	The use of Artificial intelligence in school science: a systematic literature review (Heeg & Avraamidou, 2023)	Educational Media International/ Q2	Some teachers demonstrate a supportive attitude toward the use of AI in science lessons, but their readiness is still not optimal, particularly regarding technological literacy, understanding of AI pedagogy, and confidence in its implementation	Teacher readiness needs to be strengthened through continuous training that not only improves technological literacy but also deepens understanding of AI-based pedagogy and builds confidence in integrating it
5.	Innovative Teaching: How Pre-service Teachers Use Artificial Intelligence to Teach Science to Fourth Graders (Abualrob, 2025)	Contemporary Educational Technology/Q1	The use of artificial intelligence by teachers can enhance science lessons in elementary schools, particularly by helping to create more interactive and contextual learning materials. Science lessons can be made engaging and easily understood by fourth-grade students, although teachers' pedagogical readiness and ability to craft AI prompts still need improvement	Specialized training is needed for teachers in designing AI prompts and integrating them into science instruction so that the application of AI does not merely assist in material creation but also enhances pedagogical quality and deepens students' conceptual understanding
6.	The Role of Artificial Intelligence (AI)-Assisted Question Generation on Preservice Science Teachers' 21st-Century Teaching Competencies (Zorlu, 2025)	Journal of Baltic Science Education/Q2	The use of AI in creating science questions enhances teachers' 21st-century skills, such as critical thinking, collaboration, and technology use, and makes learning more interactive, thereby improving teachers' readiness for technology integration	It is recommended that elementary school teachers receive training in using AI to create science questions, so they can improve the quality of interactive learning that is relevant to technological advancements

7.	The Effectiveness of Teacher Support for Students' Learning of Artificial Intelligence Popular Science Activities (Wu & Yang, 2022)	Frontiers in Psychology/ Q1	The success of AI-based science learning depends heavily on teachers' readiness to provide instructional support. Teachers who are pedagogically and technologically prepared can enhance students' understanding of scientific concepts and learning outcomes through interactive, problem-solving-based AI activities.	Elementary school teachers need to improve their readiness in integrating AI, both pedagogically and technologically, and be able to adjust the level of support so that science learning remains effective and fosters students' independent thinking.
8.	Science Teachers' Perceptions of the Artificial Intelligence in Science Education: Challenges, Readiness, Benefits, and Impact on Student Learning (Efe & Aslan, 2025)	Journal of Baltic Science Education/Q2	Science teachers have a positive perception of the use of AI in science education because it enhances conceptual understanding, visualizes abstract concepts, and increases student engagement. However, teachers' readiness is still limited by insufficient training, inadequate infrastructure, and low technological literacy.	There is a need for continuous professional development and the provision of adequate infrastructure so that teachers can optimize the use of AI in science education and enhance student engagement and understanding.
9.	Task/Technology Fit or Technology Attraction? The Intentions of STEM Teachers to Use AI Technologies for Teaching Innovation (Chen et al., 2025)	The Asia-Pacific Education Researcher /Q1	STEM teachers' readiness and intentions to use AI in teaching, including science, are influenced by the fit between the technology and learning needs (task-technology fit) and their attraction to the technology itself. AI has proven to have the potential to enhance science learning innovation, particularly in the presentation of content and more interactive learning activities.	Support for strengthening pedagogical competencies and integrating AI into learning objectives is essential to ensure that the resulting innovations are more effective and meaningful.
10.	Acceptance of Artificial Intelligence in Teaching Science: Science Teachers' Perspective (Al Darayseh, 2023).	Computers and Education: Artificial Intelligence /Q1	Teachers demonstrate a high level of acceptance toward the application of AI in science lessons. Teachers' readiness is reflected in high levels of self-efficacy, positive attitudes, and perceptions.	There is a need to enhance training programs and strengthen teachers' competencies, particularly in the use of AI for science education, so that teachers' readiness

			of the ease and benefits of using AI.	extends beyond mere attitude to the actual implementation of activities in the classroom
--	--	--	---------------------------------------	--

The use of Artificial Intelligence (AI) in elementary science education shows strong potential to support educational transformation, especially in terms of teacher readiness to integrate this technology. Studies indicate that teachers generally have positive attitudes toward AI, but their readiness varies, with limitations in technological literacy, understanding of AI-based pedagogy, and confidence in classroom application (Heeg & Avraamidou, 2023; Park et al., 2023). AI can support the creation of interactive and contextual learning materials (Abualrob, 2025)., and its use in tasks such as question design can also enhance teachers' 21st-century skills, including critical thinking, collaboration, and digital literacy (Zorlu, 2025), showing that AI contributes to the ongoing development of teacher readiness

Furthermore, the success of AI-based learning in elementary science education is largely determined by teachers' readiness, particularly in providing appropriate pedagogical and technological support, which can enhance students' conceptual understanding, engagement, and learning outcomes through interactive activities (Wu & Yang, 2022; Efe & Aslan, 2025). AI also contributes to more systematic and accurate assessment processes, enabling teachers to better monitor student progress and supporting the development of adaptive, data-driven evaluation systems (Huang, 2022) (Zorlu, 2025). Although teachers generally show positive attitudes, high acceptance, and perceived benefits of AI use (Al Darayseh, 2023), their competencies remain limited due to insufficient training, low technological literacy, and infrastructure constraints (Alshorman, 2024; Efe & Aslan, 2025). Therefore, effective AI integration requires alignment between technology, learning objectives, and teachers' pedagogical readiness to ensure optimal impact on science education (Chen et al., 2025)

Based on a synthesis of these various findings, it can be concluded that elementary school teachers' readiness to integrate Artificial Intelligence (AI) into science education falls into the "adequate" category, particularly in terms of their attitudes, interest, and acceptance of the technology, which tend to be positive. However, in terms of technical and pedagogical competencies, this readiness remains uneven and needs to be improved. Teachers still require strengthening in technological literacy, AI-based instructional design, and the ability to effectively utilize AI in the learning and assessment processes. Additionally, constraints such as limited infrastructure and a lack of training also pose barriers to implementation. Therefore, sustained efforts through training, competency enhancement, and support for facilities and infrastructure are necessary to ensure that the integration of AI into science education can be implemented optimally and sustainably.

The findings reveal a paradox: elementary school teachers generally have positive attitudes toward Artificial Intelligence (AI), yet their technical and pedagogical competencies remain low. This aligns with the Technology Acceptance Model, where perceived benefits encourage acceptance even when implementation skills are limited, as teachers see AI as helpful for administration, media creation, and personalized learning (Heeg & Avraamidou, 2023; Park et al., 2023). However, low digital literacy,

limited training, and lack of clear guidelines hinder its effective use (Alshorman, 2024; Efe & Aslan, 2025). As a result, AI use is still limited to basic tasks and has not fully supported curriculum goals such as differentiated learning, indicating the need to align teacher competencies, instructional design, and curriculum implementation so AI can truly transform science education (Chen et al., 2025).

Elementary School Teachers’ Readiness to Address the Transformation of Science Education through Artificial Intelligence (AI)

Artificial Intelligence (AI) is increasingly used in elementary science education as it supports interactive, adaptive, and data-driven learning, helping students understand concepts through visualization, simulations, and immediate feedback (Gontina & Asyhar, 2023; Siagian & Sofiyah, 2024; Prima et al., 2025; Kuang et al., 2025; Muzaki et al., 2025; Tang, 2024). However, its successful integration depends on teacher readiness, including knowledge, skills, and attitudes toward technology, where teachers must be able to understand and apply AI in effective learning strategies (Ayanwale et al., 2022; Yulianto et al., 2025; Guo, 2025; McBean, 2025; Nasrah et al., 2025). In Indonesia, this remains a challenge due to uneven and still-developing digital literacy, highlighting the need for continuous training and supportive policies to strengthen teachers’ competencies.

Teachers’ attitudes and acceptance of Artificial Intelligence (AI) are crucial for its integration into elementary science education (Guo, 2025; McBean, 2025). While many teachers view AI positively for making learning more interactive and supporting concept understanding, some remain hesitant due to limited experience and knowledge (Guo, 2025; McBean, 2025; Nasrah et al., 2025). Additionally, gaps in technical and pedagogical competencies show that teachers need balanced training to effectively integrate AI into meaningful learning (Gontina & Asyhar, 2023; Siagian & Sofiyah, 2024). In Indonesia, AI implementation presents opportunities but also challenges, such as uneven digital literacy and limited infrastructure, especially in 3T areas (Kurniawati et al., 2025; Murwani et al., 2025). Therefore, policies, training, and infrastructure support are needed to ensure equitable and effective use of AI in science learning (Kaswar et al., 2023; Kurniawati et al., 2025; Murwani et al., 2025).

Although the ten articles analyzed are mostly from a global context, the findings remain relevant to elementary education in Indonesia, particularly in assessing teachers’ readiness for AI-driven digital transformation, which varies due to differences in age, experience, access to technology, and digital literacy, especially between urban and 3T areas; therefore, strengthening digital and pedagogical competencies, providing contextual training, and implementing adaptive policies are essential for equitable AI integration. AI in science education can enhance student engagement, conceptual understanding, and critical thinking (Alim & Butsiarah, 2025; Tahir et al., 2025), but challenges such as limited digital literacy, lack of training, and inadequate facilities require continuous support through training, infrastructure, and policy. Overall, this SLR highlights both theoretical and practical implications for developing innovative, technology-based science learning, although it is limited by the number of studies, varied contexts, and focus on cognitive aspects, suggesting future research should broaden scope and explore AI implementation more deeply across contexts and levels.

▪ **CONCLUSION**

Based on the research findings, it was concluded that elementary school teachers' readiness to address the transformation of science education using Artificial Intelligence (AI) falls into the "adequate" category. This is evident from the teachers' attitudes, interest, and acceptance, which tend to be positive toward the use of AI in education. However, in terms of technical and pedagogical competencies, this readiness remains suboptimal and uneven. Limited digital literacy, a lack of ongoing training, and insufficient support for facilities and infrastructure are the main obstacles faced. Therefore, systematic efforts are needed to develop teachers' skills so that the implementation of AI in science education can proceed effectively and to the fullest extent possible.

It is recommended that the government and educational institutions provide ongoing training focused on enhancing teachers' technical and pedagogical competencies in utilizing AI. Additionally, schools need to improve infrastructure support and ensure adequate access to digital technology. Teachers are also expected to actively develop digital literacy and innovative skills in designing AI-based learning. On the other hand, future researchers are encouraged to conduct direct empirical field studies to examine the implementation of AI in science education in a more in-depth and contextual manner, thereby providing a comprehensive description

▪ REFERENCES

- Abualrob, M. M. (2025). Innovative Teaching: How Pre-Service Teachers use Artificial Intelligence to Teach Science to Fourth Graders. *Contemporary Educational Technology*, 17(1), 547-567. <https://doi.org/10.30935/cedtech/15686>
- Al Darayseh, A. (2023). Acceptance of Artificial Intelligence in Teaching Science: Science Teachers' Perspective. *Computers and Education: Artificial Intelligence*, 4, 100132. <https://doi.org/10.1016/j.caeai.2023.100132>
- Alkan, A. (2024). Artificial Intelligence: Its Role and Potential in Education. *Journal of the Human and Social Science Researches (Itobiad)*, 13(1), 483-497. <https://doi.org/10.15869/itobiad.1331201>
- Alshorman, S. (2024). The Readiness to Use AI in Teaching Science: Science Teachers' Perspective. *Journal of Baltic Science Education*, 23(3), 432-448. <https://doi.org/10.33225/jbse/24.23.432>
- Angelia, Y., Supeno, S., & Suparti, S. (2022). Keterampilan Proses Sains Siswa Sekolah Dasar dalam Pembelajaran IPA Menggunakan Model Pembelajaran Inkuiri. *Jurnal Basicedu*, 6(5), 8296-8303. <https://doi.org/10.31004/basicedu.v6i5.3692>
- Anwar, N. M., Amin, S. J., & Akib D, Muh. (2025). Respons dan Kesiapan Guru Madrasah dalam Menghadapi Transformasi Pembelajaran Berbasis Teknologi: Studi Kualitatif di Madrasah Aliyah DDI Galla Raya Raya. *Jurnal Pendidikan dan Teknologi Indonesia*, 5(9), 2730-2740. <https://doi.org/10.52436/1.jpti.1098>
- Aprianto, I., Sofyan, S., Rahmawati, S., & Sufyadi, S. (2025). Artificial Intelligence and its Effects on Critical Thinking and Problem-Solving Abilities in Higher Education. *Indonesian Journal of Educational Development (IJED)*, 6(3), 704-719. <https://doi.org/10.59672/ijed.v6i3.5030>
- Ayanwale, M. A., Sanusi, I. T., Adelana, O. P., Aruleba, K. D., & Oyelere, S. S. (2022). Teachers' Readiness and Intention to Teach Artificial Intelligence in Schools.

- Computers and Education: Artificial Intelligence*, 3, 100099. <https://doi.org/10.1016/j.caeai.2022.100099>
- Azim, R. (2025). Teacher Readiness in the Face of the Fifth Industrial Revolution: A Human-Centred Technological Paradigm in Education. *International Education Trend Issue*, 3(2), 90-99. <https://doi.org/10.56442/ieti.v3i2.1262>
- Alim, B., & Butsiarah, B. (2025). The Application of AI-Assisted Project-Based Learning to Improve Students' Critical Thinking Skills. *DIAJAR: Jurnal Pendidikan Dan Pembelajaran*, 4(4), 818-827. <https://doi.org/10.54259/diajar.v4i4.5788>
- Boltaeva, S. O. (2025). Prospects For The Development Of Digital Education Based On Artificial Intelligence. *International Journal of Pedagogics*, 5(09), 209-212. <https://doi.org/10.37547/ijp/Volume05Issue09-55>
- Cabral, A., & Palavras, S. (2025). Artificial Intelligence in Educational Contexts: Teachers' Perspectives from a Systematic Literature Review. *Journal of Technologies Information and Communication*, 5(2), 36004. <https://doi.org/10.55267/rtic/16727>
- Chen, J., He, X., Ning, Y., Wijaya, T. T., & Liu, J. (2025). Task/Technology Fit or Technology Attraction? The Intentions of STEM Teachers to Use AI Technologies for Teaching Innovation. *Asia-Pacific Education Researcher*, 34(1), 50-64. <https://doi.org/10.1007/s40299-024-00789-7>
- Efe, R., & Aslan, H. (2025). Science Teachers' Perceptions of the Artificial Intelligence in Science Education: Challenges, Readiness, Benefits, and Impact on Student Learning. *Journal of Baltic Science Education*, 24(4), 655-669. <https://doi.org/10.33225/jbse/25.24.655>
- Gontina, W., & Asyhar, R. (2023). Dampak Artificial Intelligence Terhadap Pembelajaran IPA/Fisika di Sekolah. *Silampari Jurnal Pendidikan Ilmu Fisika*, 5(2), 238-250. <https://doi.org/10.31540/sjpif.v5i2.2609>
- Guo, J. (2025). Research on the Role Transformation and Teaching Strategies of College English Teachers under the Background of Artificial Intelligence. *Frontiers in Educational Research*, 8(8), 114-123. <https://doi.org/10.25236/FER.2025.080807>
- Hanafi, J., & Komalasari, A. (2025). Penerapan Model Pembelajaran Think Pair Share (Tps) Untuk Meningkatkan Kemampuan Berpikir Kritis Peserta Didik Pada Pelajaran Ipa. *Al Ibtidaiyah*, 06(02), 54-67. <https://doi.org/10.76436/alibti.v6i2.67890>
- Hariyanto, Kristianingsih, F. X. D., & Maharani, R. (2025). Artificial Intelligence in Adaptive Education: A Systematic Review of Techniques for Personalized Learning. *Discover Education*, 4(1), 458-465. <https://doi.org/10.1007/s44217-025-00908-6>
- Hashim, S., Omar, M. K., Ab Jalil, H., & Mohd Sharef, N. (2022). Trends on Technologies and Artificial Intelligence in Education for Personalized Learning: Systematic Literature Review. *International Journal of Academic Research in Progressive Education and Development*, 11(1), 884-903. <https://doi.org/10.6007/IJARPED/v11-i1/12230>
- Heeg, D. M., & Avraamidou, L. (2023). The use of Artificial Intelligence in School Science: A Systematic Literature Review. *Educational Media International*, 60(2), 125-150. <https://doi.org/10.1080/09523987.2023.2264990>

- Huang, X. (2022). Application of Artificial Intelligence APP in Quality Evaluation of Primary School Science Education. *Educational Studies*, 50(6), 73-84. <https://doi.org/10.1080/03055698.2022.2066462>
- Ismail, A., Aliu, A., Ibrahim, M., & Sulaiman, A. (2024). Preparing Teachers of the Future in the Era of Artificial Intelligence. *Journal of Artificial Intelligence, Machine Learning and Neural Network*, (44), 31–41. <https://doi.org/10.55529/jaimlnn.44.31.41>
- Kaswar, A. B., Nurjannah, Arsyad, M., Surianto, D. F., & Rosidah. (2023). Membangun Keterampilan Pendidik Melalui Pelatihan Pembuatan Media Pembelajaran Berbasis Artificial Intelligence. *Vokatek : Jurnal Pengabdian Masyarakat*, 1(3), 293–297. <https://doi.org/10.61255/vokatekjp.m.v1i3.248>
- Prima, F. K., Sayiful, R. A., Fauziahtul, A. P., Ashar, F., & Okta, W. E. (2025). An In-Depth Look At Artificial Intelligence In Education. *Data and Metadata*, 4(2), 12-42. <https://doi.org/10.56294/dm20251242>
- Naimah, K. (2022). Inovasi Pembelajaran IPA SD dengan Pemanfaatan Media KIT Alat Sederhana yang Berasal dari Lingkungan Sekitar Untuk Meningkatkan Kompetensi dan Kreativitas Siswa. *Formosa Journal of Science and Technology*, 1(2), 89-97. <https://doi.org/10.55927/fjst.v1i2.69>
- Kuang, M., Li, J., & Zheng, L. (2025). Exploration of an Interdisciplinary Teaching Model in Primary Schools Supported by Generative Artificial Intelligence. *Journal of Modern Educational Theory and Practice*, 2(5), 672-686. <https://doi.org/10.70767/jmetp.v2i5.672>
- Kurniawati, A., Ningsih, P. R., & Rahmawati, A. D. (2025). Innovative AI-Based Digital Learning through E-Books and Videos: A Strategy to Support the Merdeka Curriculum in Primary Schools. *Journal of Action Research in Education*, 3(1), 1–11. <https://doi.org/10.52620/jare.v3i1.179>
- McBean, T. (2025). Teachers’ Perspectives and Use of Artificial Intelligence in Pedagogy. *International Journal of Social Science Research and Review*, 8(11), 19–34. <https://doi.org/10.47814/ijssrr.v8i11.3048>
- Octavio, M. F. G., & Leocadio, F. G. (2025). Artificial Intelligence as a Pedagogical Resource in Initial Teacher Training. *LatIA*, 3(3), 367-376. <https://doi.org/10.62486/latia2025367>
- Tahir, M. S., Qurat, U., & Aneeqa, L. (2025). Explore the role of Artificial Intelligence on Students’ Critical Thinking and Problem-Solving Skills at higher Education Institution in Pakistan. *Social Science Review Archives*, 3(3), 2367–2378. <https://doi.org/10.70670/sra.v3i3.1084>
- Murwani, S., Syarifuddin, & Jaenudin, R. (2025). Development of AI-Based Hypercontent E-LKPD for IPAS Learning in Grade V Elementary School. *Jurnal Penelitian Pendidikan IPA*, 11(8), 1167–1173. <https://doi.org/10.29303/jppipa.v11i8.12403>
- Muzaki, H., Susanto, G., Andajani, K., Widyartono, D., Suherjanto, I., Dewi, B. C. A., & Nardiawan, L. P. (2025). Pelatihan Pembuatan Media Pembelajaran dengan Bantuan Kecerdasan Buatan (AI) untuk Pengajar dan Calon Pengajar BIPA. *Jurnal Pengabdian Masyarakat Bhinneka*, 4(1), 861–870. <https://doi.org/10.58266/jpmb.v4i1.552>
- Nasrah, S., Milfayetty, S., Rahman, A., & Muthmainnah, M. (2025). Strategic Approaches to Enhancing Teacher Competence in Artificial Intelligence for the

- Transformation of 21st Century Education. *Journal of International Conference Proceedings*, 8(2), 41–53. <https://doi.org/10.32535/jicp.v8i2.4158>
- Nugroho, O. F., Hikmawaty, L., & Juwita, S. R. (2024). Artificial Intelligence Technology Embedded in High School Science Learning: A Study of Teacher Perception. *Pedagonal: Jurnal Ilmiah Pendidikan*, 8(2), 132–143. <https://doi.org/10.55215/pedagonal.v8i2.16>
- Orujlu, A. (2025). Evolution of Language Teaching Methodologies: From Grammar-Translation to Communicative Approaches. *Global Spectrum of Research and Humanities*, 2(5), 144–155. <https://doi.org/10.69760/gsrh.0250205017>
- Park, J., Teo, T. W., Teo, A., Chang, J., Huang, J. S., & Koo, S. (2023). Integrating artificial intelligence into science lessons: Teachers' experiences and views. *International Journal of STEM Education*, 10(1), 61–69. <https://doi.org/10.1186/s40594-023-00454-3>
- Parno, P., & Agustinus, D. Y. (2022). E-Learning Berbasis Android Memanfaatkan Augmented Reality (Studi Kasus: Pelajaran IPA Sekolah Dasar Materi Planet Tata Surya). *ikraith-informatika*, 7(2), 22–48. <https://doi.org/10.37817/ikraith-informatika.v7i2.2248>
- Pazmiño Constante, P. G., Romero Pacheco, D. E., Roldán Saltos, Y. D. R., Ceballos Torres, C. C., & Alcívar Cedeño, R. A. (2024). Impacto del uso de Tecnologías Educativas en la Motivación Y el Compromiso Estudiantil Durante el Proceso de Aprendizaje: Impact Of The Use Of Educational Technologies On Student Motivation And Engagement During The Learning Process. *LATAM Revista Latinoamericana de Ciencias Sociales y Humanidades*, 5(4), 22–34. <https://doi.org/10.56712/latam.v5i4.2240>
- Purba, G. E., Nasution, I. R., & Simanjuntak, M. P. (2025). Analisis Paradoks Pembelajaran IPA dan Desain Solusi Hybrid Blended Learning di Sekolah Menengah. *Journal Research and Education Studies*, 6(3), 890–899. <https://doi.org/10.51178/invention.v6i3.2917>
- Rahangmetan, D. A. P., Leuwol, F. S., & Lasaiba, M. A. (2025). Pemanfaatan Kecerdasan Buatan (Artificial Intelligence) untuk Peningkatan Kualitas Pembelajaran di SMP Negeri 2 Ambon Melalui Pelatihan Guru. *Jurnal Pengabdian Arumbai*, 3(1), 1–11. <https://doi.org/10.30598/arumbai.vol3.iss1.pp1-11>
- Ratih, D., Purwoko, B., Gunansyah, G., Nasution, N., & Mariana, N. (2025). Trends in Wordwall Integration for Elementary IPAS Learning: A Systematic Literature Review. *Journal of Innovation and Research in Primary Education*, 4(4), 3648–3659. <https://doi.org/10.56916/jirpe.v4i4.2394>
- Rustandi, J., Ansori, M. R., Fahlepi, R., Iriansyah, I., & Marliat, M. (2024). Teacher Competence in the Digital Era A Phenomenological Study. *Jurnal Konseling Pendidikan Islam*, 5(2), 527–534. <https://doi.org/10.32806/jkpi.v5i2.212>
- Sadykova, G., & Kayumova, A. (2024). Educators' Perception of Artificial Intelligence as Instructional Tool. *TEM Journal*, 3(2), 3194–3204. <https://doi.org/10.18421/TEM134-54>
- Shambhavi, S., Gadade, A., Birajdar, A., & Jagtap, A. (2025). AI Personal Study Buddy: A Web-Based Adaptive Learning and Summarization Platform for Smart

- Academic Support. *International Journal Of Scientific Research In Engineering And Management*, 09(11), 1–9. <https://doi.org/10.55041/IJSREM53431>
- Siagian, S. K., & Sofiyah, K. (2024). Implementasi Artificial Intelligence Dalam Mengembangkan Kemampuan Belajar, Kompetensi, dan Kreativitas Siswa Sekolah Dasar di Era Digitalisasi. *EDUCATIONAL : Jurnal Inovasi Pendidikan & Pengajaran*, 4(1), 14–19. <https://doi.org/10.51878/educational.v4i1.2894>
- Sidabalok, D. N., Khoirunnisa, N., Devi, T. B., & Syahrial, S. (2025). Studi Literatur Evaluatif: Strategi dan Tantangan Pembelajaran IPA di Sekolah Dasar. *GURUKU: Jurnal Pendidikan dan Sosial Humaniora*, 3(2), 240–244. <https://doi.org/10.59061/guruku.v3i2.997>
- Tang, K. H. D. (2024). Implications of Artificial Intelligence for Teaching and Learning. *Acta Pedagogica Asiana*, 3(2), 65–79. <https://doi.org/10.53623/apga.v3i2.404>
- Ulfha, M., Sumarni, W., Subali, B., & Widiarti, N. (2025). Tinjauan Literatur Sistematis: Pengembangan Storybook sebagai Media Pembelajaran Sekolah Dasar (2019-2024). *Didaktika: Jurnal Kependidikan*, 14(3), 559-565. <https://doi.org/10.58230/27454312.2353>
- Wu, S.-Y., & Yang, K.-K. (2022). The Effectiveness of Teacher Support for Students' Learning of Artificial Intelligence Popular Science Activities. *Frontiers in Psychology*, 13(2), 868-876. <https://doi.org/10.3389/fpsyg.2022.868623>
- Yulianto, D., Juniawan, E. A., Junaedi, Y., Astari, & Nurcahyo, R. (2025). Modeling the Determinants of AI Integration in Primary Mathematics Education: A Structural Equation Modeling Analysis. *Jurnal Elemen*, 11(4), 912–929. <https://doi.org/10.29408/jel.v11i4.30518>
- Zorlu, Y. (2025). The Role Of Artificial Intelligence (AI)-Assisted Question Generation on Preservice Science Teachers' 21st-Century Teaching Competencies. *Journal of Baltic Science Education*, 24(5), 984-1005. <https://doi.org/10.33225/jbse/25.24.984>